Regional preferences and accepted practices in urban stream restoration: An overview of case studies.

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Abstract

The modernization of society and the growth of urban areas have led to a subsequent decline in the quality of urban watersheds and riverine ecosystems. However, over the last two decades, there have been significant efforts to "restore" these systems to a more natural state, reversing or mitigating the effects of development. Examples of typical urban stream restoration projects include bank stabilization, de-channelization of artificially straightened and hardened reaches, channel daylighting of closed conduit streams, dam and culvert removal, creation of stream access points, and habitat improvement. The planning and design of these projects have largely been regional in nature with local and regional authorities, public interest groups, and engineering companies involved. As such, the potential for regional preferences and accepted practices exists. This paper will investigate regional differences as well as similarities in urban stream restoration projects by examining case studies throughout the United States. This effort seeks to define the "State of Practice" for urban stream restoration across the United States and provide a platform for discussion on regional preferences. It is envisioned that much can be gained from sharing information between regions, however, the social, economic, political, physical, and climatic differences must be considered in the planning and design of urban stream restoration projects.

Introduction

The degradation of urban streams is a result of modified hydrologic, sediment transport and morphologic conditions associated with urbanization. Urban watersheds, with varying degrees of imperviousness, tend to have a wide variety of flow regimes ranging from high peaks with short duration to low (or even no) base flows. As the amount of impervious surface increases, the frequency of bankfull flood events also increases. Furthermore, a stream's ability to connect with its floodplain tends to be more difficult due to changing hydrologic conditions, channel bed and bank degradation, physical changes to the streams (relocated sections or floodplain fill), placement of man-made structures, and loss of riparian vegetation. In addition to hydrologic changes, urban streams tend to be more confined due to infrastructure. Frequent transportation crossings and utilities, particularly gravity sewer lines, are located in or across historic floodplains. Urban streams tend to have more structures such as culverts and bridges, and in some cases dams. These structures alter flow hydraulics and may further limit access to floodplains. In extreme cases, development may have eliminated floodplain access.

Changing sediment regimes in urban streams can also have dramatic effects on the form of a stream. High sediment loads with finer particle sizes are often produced in developing areas and can enter the stream environment during storm events. The hydrologic changes caused by development can also destabilize urban streams, accelerating local bank erosion. Urban streams can also suffer from the opposite extreme, sediment starvation or hungry water, and thus erode the bed resulting in an incised channel. It is not unusual to find areas of extreme scour and other areas of rapid aggradation in the same urban river system.

Urban streams can also suffer significant water quality problems. In addition to increased sediment loads, storm flows flush nutrients, oils, and metals out of the atmosphere and off of impervious surfaces into streams. Fecal coliform contamination is common in urban areas, where wastewater treatment facilities cannot keep pace with community growth and old septic systems fail. In addition to chemical pollution, thermal pollution can cause habitat degradation. Heat from rooftops and blacktop pavements is absorbed by the rainfall and runoff and these heated waters enter channel systems. These problems can then be further acerbated by the loss of riparian vegetation and high width/depth ratios (low base flows cover a wider area at a shallower depth). Thermal pollution is a major concern in streams that historically support cold-water fisheries.

Implementation of stream restoration activities in urban watersheds are motivated by agencies, individuals, and groups wanting to alleviate the problems and issues listed above. Examples of typical urban stream restoration projects include bed and bank stabilization, adding meanders to straightened reaches, channel daylighting of closed conduit streams, dam and culvert removal, and habitat improvement. The planning and design of these projects tends to be local in nature so there exists potential for regional preferences and accepted practices. Varying regional activity is the impetus behind this paper, which was written by a subgroup of the Environmental and Water Resources Institute's River Restoration Technical Committee whose focus is on urban streams and watersheds. This group seeks to define the "State of Practice" of urban stream restoration across the United States. To illuminate regional differences, this paper investigates case studies in an effort to define regional practices. It is envisioned that much can be gained from sharing information between and within regions, however, the social, economic, political, physical, and climatic differences must be considered in the planning and design of urban stream restoration projects.

For this paper, the continental United States was divided into eight regions based primarily on geography (Pacific Northwest, California, Southwest, Midwest, Great Lakes, Southeast, Mid-Atlantic, and Northeast). For each region, a literature search and Internet search were performed to determine the state of practice of urban stream restoration for that region. A significant amount of information on river restoration can be found on the Internet and an Internet summary section is located at the end of this paper. In many cases, personal communication with regional authorities and design experts was also part of the process. Each regional section represents a sample of restoration activities in that region and should not be viewed as a comprehensive picture, but rather as a starting point for increased dialog within and between regions. A reference list can be found at the end of the paper along with an acknowledgements section. Many individuals provided information for this paper so we apologize to anyone omitted.

Established Urban Stream Restoration Techniques

Stream restoration projects include reintroducing meanders to straightened reaches using a "natural" channel design approach, channel daylighting of closed conduit streams, bed and bank stabilization, dam and culvert removal, and habitat improvement. The "natural" channel design approach analyzes existing channel form, and prescribes a planform alignment consisting of meander wavelength and radius of curvature, a cross-sectional area from hydraulic geometry relationships, and riffle spacing for bed structure (Rosgen 1996). If land space near stream is available, reconnection of the floodplain occurs as part the overall project. Daylighting of a channel that has been forced into a closed conduit is more problematic, because restoring the channel to "natural" condition typically cannot be achieved within the existing constraints imposed by urban development. However, daylighting projects are a popular form of urban stream restoration and projects have been completed from coast to coast (Pinkham, 2000).

Stabilization of the streambed through hydraulic grade control measures is major focus of stream restoration work because hydrological changes often lead to stream degradation. In channel (or in-stream) structures that have typically been used to stabilize the bed include Newbury weirs or riffles (Newbury and Gaboury 1993), step-pool structures, gabions, and weir structures constructed of wood or rock.

Bank stabilization is a key component of almost all urban stream restoration practices because of increased lateral erosion. Bank stabilization includes structures to either armor against or divert high-velocity flows away from banks, particularly at bends were the bank toe is especially vulnerable to erosion. In-channel structures that are typically used to stabilize the bank include boulder placements at the bank toe, vortex rock weirs, log vanes, woody debris and root wads. Bioengineering approaches on the channel side slopes include planting trees and grass, live staking (live branch layering) and tree revetments. Other bioengineering practices include terracing, the use of biodegradable erosion control blankets and non-degradable geotextile (filter fabric) before vegetation gets established, brush bundles and coconut fiber bio-logs at the toe of the channel bank, bank riprap covered with topsoil and mulch, and organic soil amendments. These approaches are more aesthetically pleasing than “hard” engineered approaches such as concrete retaining walls and gabions.

Reconnecting a channel to its floodplain is typically accomplished by modifying the channel cross-sectional shape coupled with raising the bed invert as part of the “natural” channel design protocols. This approach often requires excavation in the floodplain to achieve a more natural hydraulic geometry. This cross-sectional modification is always coupled with raising the streambed invert by using hydraulic grade controls, such as riffle weirs. Another approach is creating an intermediate floodplain bench within an incised channel. In urban environments raising the channel bed is not always acceptable from a flood control perspective. Therefore a way to meet flood and erosion control goals an multi-objective approach would be to stabilize the incised channel with grade control and to develop an intermediate floodplain bench within the incised floodway.

In some cases, in-stream habitat enhancement is a goal of the restoration project and in other cases it is a by-product of channel stabilization approaches. Habitat enhancement structures include pool-riffle structures, step-pool structures, boulder placements, large woody debris, root wads, bottomless arch culverts for safer fish passage and lunker boxes. These features provide diversity in the streambed and improve habitat for various species.

For more information on stream restoration techniques, the Stream Corridor Restoration Manual by the Federal Interagency Stream Restoration Working Group provides an excellent overview of the subject (Federal, 1998). Also, the U.S. Army Corps of Engineers has produced an engineering manual on the subject; Hydraulic Design of Stream Restoration Projects (Copeland, 2001). However, designers should use caution when determining restoration technique viability since many accepted stream restoration practices for rural environments are not applicable to urban settings (Fischenich, 2001). A review of urban stream restoration techniques can be found in Urban Stream Assessment by Brown (2000). The techniques covered by Brown are common across a majority of the United States.

Regional Information

Pacific Northwest

The driving factor for a majority of river restoration projects in the Pacific Northwest is salmonid migration in which several species are listed as endangered. As such, urban stream restoration projects within the region are frequently concerned with salmonid migration in addition to water quality, aesthetics, fish and wildlife habitat, resident endangered species, and bank stabilization (Booth et al., 2002). For the purpose of this paper, the Pacific Northwest was essentially limited to Washington and Oregon. Aggressive stream restoration programs and projects are in place in both Portland and Seattle, two major urban centers within the region.

One recent ambitious project in the Portland, Oregon Metropolitan Area was the restoration of Springbrook Creek. The stream suffered from extensive downcutting and bank erosion, which has caused the stream to be disconnected from its natural floodplain. In 2001, the City of Lake Oswego initiated restoration of a 2600 ft long section of the creek with project objectives that included a restoration of the natural stream channel stability, a dissipation of stream power, improved water quality, and enhanced fish and wildlife habitat. Rosgen's methodology was used to classify and assess the stream and design the restored channel based on bankfull hydraulic geometry data from other sites in Oregon and Washington. Historic photographs and topographic maps were used to insure the proposed natural channel design for the site was in range of the historic dimensions, pattern, and profile. The project included boulder and log cross vanes and barbs to redirect flow and log and boulder revetments to prevent the stream from reacquiring the abandoned channel (Harris 2002, Doneker et al. 2002).

Another regional project involves numerous restoration sites within the adjacent Fanno and Tryon Creek watersheds in Portland. The City of Portland Bureau of Environmental Services completed eleven restoration projects between 1994 and 2001 within these two watersheds to restore channel shape, channel function, water quality and habitat. In some cases, restoration was also required to protect infrastructure from severe bank erosion and/or channel downcuttting. The restoration of these sites was performed in context with the city's formal process for assessment of streams in which land use, stream condition, riparian habitat, and water quality are used to establish a site's restoration priority. Restoration techniques utilized in these projects included bioengineering stabilization techniques, bank and bed stabilization using boulders, channel realignment, and rootwad habitat improvements (Wahab, 2002).

In the State of Washington, there have been numerous stream restoration projects in the Seattle Metropolitan Area. Almost all of the streams within the city have been degraded due to urbanization. Problems in Seattle include bank erosion, clogged spawning gravel, migration barriers, stormwater runoff and water quality. Urbanization has caused a decline in the Chinook salmon migration runs that were once common in these streams. This prompted Seattle Public Utilities to undertake habitat restoration of 5 streams in the region (Piper's Creek, Thornton Creek, Taylor Creek, Fauntleroy Creek, and Longfellow Creek). The goal of all of these rehabilitation projects was to improve salmon spawning and rearing habitat, stabilize stream banks, remove migration barriers, restore natural riparian vegetation, and increase public awareness. The first step in rehabilitating these systems was to control detrimental stormwater runoff. At several locations, stormwater outfall pipes were retrofitted and peak flows were diverted in detention ponds and constructed wetlands to regulate the amount of water flowing into the streams. Habitat in these streams was then improved by narrowing and deepening the channels by installing log and rock weirs as bed controls, deflector logs to narrow the channel, and rootwads to create pool habitat. Stream bank erosion was controlled utilizing boulders, logs, and bioegineering techniques such as matting and live staking. To improve fish passage and migration, culverts were modified on several of these creeks where existing circular culverts were replaced with bottomless arch culverts to maintain bottom structure. On Fauntleroy Creek, baffled fish ladders were constructed on either side of the culvert to improve fish passage (Gresham, 2002).

California

The State of California was granted regional status due to the numerous stream restoration projects in the ground and multitude of active watershed coalitions organizing projects. According to the California Water Resources Department Urban Streams Restoration Program, urban stream projects have evolved from solutions to flooding problems in the mid-1980's to coordinated water management plans and watershed level approaches to urban stream restoration (Malchow, 2003). The San Francisco Bay Regional Water Quality Control Board has published a technical reference on stream protection (Riley, 2002) that outlines the links between water quality and channel stability and discusses practices to stabilize channels. Mitigation is not the only driving force behind the restoration movement, but rather state available funds and an environmentally conscious population, interested in improving aesthetics and ecological function while renovating town centers and reducing flooding in their communities. Communities and watershed coalitions compete for funds from the Department of Water Resources to complete stream restoration projects. In addition to community driven projects, the Environmental Enhancement and Mitigation Program, established by the state legislature in 1989, offers millions of dollars each year for projects to mitigate environmental impacts caused by new or modified state transportation facilities.

Urban stream restoration approaches in California involve bank stabilization, removal of fish barriers and habitat enhancement, removal of concrete lining and daylighting pipes, geomorphological channel design, and riparian replanting. Examples of urban stream restoration in California are wide and varied. One of the oldest and most well-known stream projects in California is the daylighting of Strawberry Creek in Berkeley in 1984. In this case, and old rail yard was converted into a four-acre urban park. Channel geometry estimates were taken from observations of a free-flowing portion of Strawberry Creek flowing through the University of California, which is located several blocks upstream of the restoration site. Investigation of local soils after removal of the culvert helped determine the location historic creek meanders. Excavated material was used on site and native trees and herbaceous vegetation were planted. Funding is in place to ensure continued maintenance of the grounds and riparian vegetation (Pinkham 2000).

Southwest

The hydrology of a majority of the Southwest (Arizona, New Mexico, Texas, Utah, Nevada) is very different than the rest of the country. The arid nature and occasional torrential rains found in the Southwest would obviously play a significant role in urban stream restoration designs. However, these states are not active in traditional urban stream restoration projects. A majority of the restoration projects that exist in these states (especially Arizona and New Mexico) revolve around habitat restoration and wetland creation along the Rio Grande and Colorado Rivers and in urban centers such as Phoenix (Gritzuk et al. 2001).

Efforts in Central Texas designate the State of Texas is the definite regional leader in urban stream restoration in the Southwest. One example is the Integrated Watershed Management Plan for the City of Austin. This plan has led to several restoration projects within the city with several more in the planning and development stages. A completed project in Austin is the restoration of Tannehill Branch of Boggy Creek that was completed in July of 2001. The objective of the project was to provide long-term maintenance of planform and grade while allowing for natural bedform variability and transport of sediment through the reach. The project consisted of a series of pool and riffle structures that provided grade stability. Bank erosion was controlled using a combination of stone toe revetments and bioengineering techniques such as brush mattresses, live plantings, and coir fiber rolls. Existing gabion bank protection in the outer meander bends were left in place to fix the planform. Additionally, the San Antonio River Improvements Project proposes to realign nearly 9 miles of stream south of the downtown area (currently in design).

Midwest

In the Midwest, there is a growing understanding that urban watershed restoration should focus on restoring natural processes that create and maintain habitat rather than manipulating in-stream habitats. Still, there is a general lack of guidance across the region that stems from limited information on the effectiveness of various habitat restoration and enhancement techniques. There is a concerted effort made by various state agencies in using stream classification and assessment guidelines as a starting point for prioritization and restoration efforts. In Colorado, Missouri, and Kansas there are guidelines in place that focus upon methodical screening criteria prior to undertaking a watershed restoration effort.

One city with active urban stream restoration projects within the Midwest is Denver, Colorado (Lloyd and Hindman 2002, Hunter and Thrush 2002, Kohlenburg and MacKenzie 2002). Denver receives annual average precipitation of 35.6 centimeters that result in developing a base flow for many streams that were ephemeral in nature. A common result of those streams with slopes larger than 0.5% is to develop a narrow trickle channel that, over time, may lead to channel entrenchment and severe erosion. Hunter and Thrush (2002) indicate that a typical storm maintenance program is likely to address the symptoms rather than cure the problems due to a relatively recent emphasis on drainage management. In the specific example of Goldsmith Gulch Channel Repair, agencies involved used boulder walls in the lower reaches to create an island to protect a large area of trees, raised the invert and reshaped two sweeping meanders to eliminate incised channels in the middle channels, and design of an upper drop structure in the upper reach. Authors indicate minor damage to wetland plants in fall storms and established wetlands within two years. This project is a good example of a flow channel improvement project that incorporated a meandering stream with shallow overbanks.

Great Lakes

In the Great Lakes region, problems and issues associated with stream degradation in urban watersheds are fairly consistent. Degradation of streams in urban watersheds includes modified hydrologic and morphologic conditions, reduced water quality, and altered riparian vegetation. Within the Great Lakes region, habitat enhancement activities differ between streams that accommodate either warm-water or cold-water fisheries. In cold-water streams containing salmon and trout, habitat enhancements include overhead cover structures, termed lunkers, which are hardwood planks raised off the streambed, and positioned at a mid-vertical water depth. Fish cover also includes root wads and bank boxes, which are also used in warm-water fish streams.

A good example of the natural channel design approach using a combination of restoration practices is the Mill Creek Project in the city of Highland Hills, Cuyahoga County, Ohio. This urban stream was entrenched and eroding laterally at an excessive rate causing undercutting and destabilization of a steep hillside near a residential community. Restoration practices included reestablishing a meander pattern relocating the channel so that it would connect with a floodplain. Hydraulic grade control structures, vortex rock weirs, were used to raise the bed elevation to reconnect the active channel with the floodplain. Bioengineering practices were used to stabilize the hill slope using root wad and rock revetments along the outside of the bend. Bank stabilization practices also consisted of live branch staking, and seeding and erosion control matting. The riparian area was replanted with native tree species, such as Red Maples, American Sycamore, and Tataran Dogwood.

Design of pool-riffle structures is a common restoration practice for fish habitat enhancement. Typically, a riffle weir structure is constructed acting as a hydraulic grade control structure that produces a backwater upstream of the structure (Newbury and Gaboury 1993). In a unique case study on the North Branch of the Chicago River, Illinois, a pool-riffle structure was designed with smooth transition between units so that a backwater would not be created hydraulically (Rodríguez et al. 2000; Schwartz et al 2002). This was an ecological design consideration, in which the objectives were to create a more natural flow pattern through the structure. Ecological criteria were developed from pre-construction bioassessment and habitat analysis that found poor fish diversity correlated with the lack of a natural pool-riffle sequence. The design approach based founded on geomorphological and hydraulic engineering principles. The design approach used a three-dimensional hydrodynamic model to test whether a helical flow pattern in the pool would occur with the proposed physical dimensions. Model output also allowed for local prediction of sediment transport, so that bed material was designed to be stable during bankfull flow, but allow for the transport of fines through the structures. Ten pool-riffle structures were constructed along a one-kilometer reach from November 2001 to early 2002, and post-construction monitoring found increased diversity in the fish community.

Southeast

Within the Southeast Region, North Carolina and Georgia have taken the lead on urban stream restoration projects in the ground. South Carolina, Kentucky, Alabama, and Tennessee are all developing urban stream restoration projects and protocols. Arkansas is taking a holistic watershed approach and is focusing resources on public outreach. Little seems to be happening directly related to urban stream restoration in Florida and Louisiana although there are many wetland and coastal restoration efforts in those two states.

Stream restoration approaches in the southeast involve bioengineering, natural channel design based on fluvial geomorphological (FGM) relationships, placement of grade control or habitat structures, daylighting, and in some cases placement of riprap or other armor. Several states have embraced a watershed approach to water quality improvement, although some work is still being done in a piecemeal fashion.

Many state agencies charged with protecting and improving water quality are using Rosgen's stream classification and assessment guidelines as a starting point for prioritization of projects and river restoration efforts. North Carolina has published several sets of regional curves and Tennessee is currently using North Carolina's regional curves as a reference although they are using local reference streams. Georgia, Alabama and Arkansas are developing regional curves and lists of reference reach streams.

The City of Charlotte, in Mecklenburg County, North Carolina has taken a strong lead in the area of stream bank stabilization and habitat enhancement as part of a comprehensive storm water program that also incorporates floodplain management, greenway coordination, structural maintenance, and water quality. Charlotte is home to over 1.3 million people in the greater metro area. It has experienced explosive growth in the last decade. Consequences of rapid urban development and effects of past channel straightening and floodplain fill include increased flooding, collapsing stream banks, excessive sediment load, blocked culverts, impaired hydraulic conductivity, land loss, poor water quality, and structures in the floodway. In an effort to rectify past impacts to its waterways, Charlotte/Mecklenburg Storm Water Services now takes a holistic watershed approach to water quality improvements that recognize streams as living systems rather than fixed systems functioning only to convey stormwater (Burg, 2002).

One example of Charlotte/Mecklenburg's stream restoration/watershed improvement efforts is the Little Sugar Creek Restoration Initiative. Little Sugar Creek is highly developed as it runs through the heart of Charlotte. Effluent from a WWTP and urban runoff are the primary sources of water quality degradation (NCDWQ, 2000) A regional effort by Mecklenburg County, NC, York County, SC and Lancaster

County, SC to improve water quality in the Catawba River Basin includes the purchase and protection of undeveloped properties along the stream corridor, installation of BMP's on both vacant and developed lands, improving public awareness through various media, and installation of a 20-mile long greenway. (Burg, 2002 and Gettys, 2002). Components of the watershed initiative include voluntary FEMA buy-out of flood-prone areas, BMP retrofits to treat stormwater, extension of a greenway, riparian corridor replanting, and stream restoration efforts. Preferential stream restoration approaches incorporate FGM principles, bioengineering, and habitat improvement rather than hard structures. The FEMA buy-out program has created space for flood storage, stormwater treatment areas, addition of stream meanders to prior straightened reaches, a greenway, and a wider vegetated riparian corridor (Burg, 2002).

Mid Atlantic

An excellent source of information on Mid-Atlantic urban stream restoration projects comes from Brown (2000) who investigated 15 projects in Maryland which has more than a 10 year history of urban stream restoration. All of the projects in Brown's study were at least two to three years old; contained a variety of restoration practices; and had drainage areas with a minimum 15% impervious coverage. Brown determined that restoration techniques utilized in Maryland could be broken into four categories: bank protection techniques, grade control structures, flow deflectors, and bank stabilization techniques. Bank protection techniques included imbricated rip-rap (used to stabilize very steep streambanks), rootwad revetments, and boulder revetments. However, it appears as if rootwad revetments are being used less frequently for bank stabilization in Maryland in recent years. Johnson et. al (2002) recommended that rootwads only be used for improvement of aquatic habitat and that existing Maryland guidelines be modified before using rootwads for bank stabilization in future restoration projects. Some problems associated with rootwad revetments included scalloped erosion pattern of the streambank between adjacent rootwads and excessive scour under and/or over the rootwads. Grade control structures include step pools (typically installed in high gradient urban streams subject to degradation from uncontrolled stormwater), rock vortex weirs (the most common structures found in the Brown study), rock weirs, log drop structures, and rock cross vanes. Of these, the rock cross vane structures seemed to best meet their intended objectives and did not have any deficiencies. Structures used to deflect flow in Maryland include wing deflectors (single & double), log vanes, rock vanes, and linear deflectors. Finally, stabilization techniques include re-grading and numerous vegetative/bioengineering practices such as coir fiber logs, live fascines, and brush mattresses.

Stream restoration has become an important environmental topic within various departments of Maryland Government agencies. The Maryland State Highway Administration Structural Hydraulics unit is using restoration and stabilization techniques to improve roadway crossings over water. The Highway Hydraulics Unit is using stream restoration as mitigation for stormwater management on roadway projects. Some regulatory agencies in Maryland are requiring natural channel design as mitigation for roadway construction impacts to stream throughout Maryland. Natural channel design techniques have been used in many of the geologic areas across the state including the fall line between the Piedmont Region of central Maryland and the Coastal Plain along the Chesapeake Bay, which includes the heavily urbanized I-95 corridor. Stream restoration is this region is particularly challenging because the area is an alluvial region with minimal slope, unconsolidated material, high deposition and heavy development in the upper portions of the watershed. Restoration techniques used in this region include rootwads to stabilize eroding banks, riparian plantings to stabilize banks and provide shade and cover for the stream, rock vanes to direct energy away from eroding banks and create pools for aquatic habitat, cross vanes to create pools and provide grade control for the stream, coir fiber logs to stabilize banks and promote riparian growth, and toe boulder revetments were additional stabilization of the base of slopes was necessary (Denniston, 1999).

In Pennsylvania, the Keystone Stream Team and the Alliance for Chesapeake Bay collaborated to publish Guidelines for Natural Stream Channel Design for Pennsylvania Waterways (Keystone, 2003) using Pennsylvania Department of Environmental Protection funding (through Section 319 of the Clean Water Act). The manual was developed to provide guidance for and promote natural channel design restoration projects in Pennsylvania. The manual was written for professionals looking for guidance, but not to serve as a “cookbook” or “how-to” manual for restoration because of the State’s diverse geography and land use patterns.

In Virginia, the Northern Virginia Soil & Water Conservation District (NVSWCD) has undertaken several stream restoration projects in Fairfax County because of excessive bed erosion and bed degradation due to urbanization of the area. All of the projects included bank stabilization utilizing bioengineering techniques such as coir fiber logs and live staking. In the case of the Kingstowne Stream restoration project, the streambed was elevated to reconnect with the floodplain and gentle meanders were restored to the system.

Northeast

In the Northeast, many rivers have been channelized, dammed, or diked for up to 300 years for land drainage, industrial water power, and flood control; and occasionally for navigation or animal draft barge canals. Today, many of the old mills, canals, and dams are obsolete and abandoned with no economic use, opening up riverfront land for reuse. Increased interest in recreation, fish passage and improved water quality stimulate restoration efforts in rural and urban areas. There has been a definite movement away from the traditional river channelization type of projects, which are now limited by environmental concerns and regulatory programs.

The type and level of channel design varies significantly from state to state. In many cases, stream restoration projects are being advocated and led by non-engineers, such as fishery biologists and conservation groups, who help introduce alternative goals and methodologies. The northeast has applied a combination of fluvial geomorphic and traditional hydraulic engineering techniques beginning in the 1970's. Many of the region's streams and rivers are non-alluvial due to shallow bedrock, glacial till soils, narrow valleys and thus behave as threshold or rigid boundary channels.

In 1999, Massachusetts initiated its River Restore Program administered by the Department of Fisheries, Wildlife and Environment. The program describes its goal as being to "reconnect natural and cultural river communities by selective removal of dams and other obstructions," and to seek ecological restoration while respecting public safety and historic preservation (Riverways Program brochure, March 2000). The River Restore Program sponsored the first modern dam removal in coastal Massachusetts in September 2002. The 10-foot high Billington Street Dam was an earth embankment structure and former mill site that blocked anadromous fish passage of alewife, herring, and shad. Portions of the impounded sediments were relocated and a narrower channel formed in the pool area prior to breaching the dam. The new channel through the former dam embankment has a riffle-like profile as it gains elevation to match the upstream channel.

Vermont has suffered significant economic and environmental damage along its rivers in recent years, including numerous watercourses that were previously channelized or realigned for flood control, highway construction, agricultural activities, and development. Much of Vermont's terrain is dominated by the Green Mountains featuring youthful headwater streams with steep gradients and narrow floodplains. These watersheds are subject to flash flooding and rare but highly concentrated sediment loads of coarse materials that are carried downstream and deposited along the higher order rivers. Today, many of the state's rivers are under distress, including channel widening and aggradation due to excess sediment loads (Cahoon & Kline, Dec. 2002. The state has researched geomorphic properties of stable natural rivers and prepared draft hydraulic geometry curves of local regime channel widths, depths, and slopes versus discharge (Vermont, 2002).

The New Hampshire Department of Environmental Services is actively involved in river restoration and management with emphasis on fish passage, habitat, and ecological values. Public education and working with non-profit conservation groups, municipalities, and landowners is an important part of local grass roots river programs. The state recently adopted new instream-flow rules to help protect water quality, aquatic habitat, and recreation. This represents a hydrology-based method of river restoration and is of great value in areas with competing water demands and limited resources. In addition, New Hampshire has formed an active River Restoration Task Force composed of local, state, and federal organizations plus conservation groups to sponsor and coordinate activities (Lindloff, 2002).

Connecticut's small land area and high population density means that its rivers have been used extensively for industrial, water supply, agriculture, and waste assimilation. Early river restoration activities in the 1980s include the simulated nature-like flood control projects and trails along Trout Brook in West Hartford and Piper Brook in Newington, with pools, riffles, variable slopes, and riparian vegetation sponsored by the Department of Environmental Protection and NRCS. Currently, the state DEP has a formal River's Program with a modest budget used to support restoration efforts. Recent projects have included aquatic habitat on Stoney Brook and Merrick Brook, numerous fish ladders, and stream bank erosion control. Connecticut's Naugatuck River Restoration Program is a major multi-faceted effort to improve a 300 square mile largely urban watershed, including treatment plant upgrades, habitat improvements, trails, and riparian plantings. The fish passage component was a major effort that has removed four dams so far, with three more pending. The engineering aspects of this restoration project had to address sediment transport, channel stability, utilities, and difficult access (Wildman and MacBroom, 2000).

Internet Resources

The Internet has provided valuable information on urban stream restoration projects, techniques and design. The following websites provide the reader with additional urban stream restoration resources:

- Rocky Mountain Institute: Watersheds, Stormwater & Stream Restoration: http://www.rmi.org/sitepages/pid277.php
- The Natural Resources Project Inventory: a database of Statewide Restoration: http://endeavor.des.ucdavis.edu/nrpi/
- The Urban Streams Restoration Program: http://www.dpla.water.ca.gov/environment/habitat/stream/usrp.html
- California Environmental Resource Evaluation System (CERES): http://ceres.ca.gov/
- City of Austin Watershed Management: www.ci.austin.tx.us\watershed\
- US EPA: www.epa.state.il.us/water/watershed/publications/
- Ohio State University: www.ag.ohio-state.edu/~streams/
- North Carolina Guidelines:http://h2o.enr.state.nc.us/ncwetlands/streamgd.pdf.
- Kentucky Division of Water: http://water.nr.state.ky.us/dow/restore.htm.
- Tennessee: http://www.state.tn.us/environment/wpc/wpcppo/index.html.
- Georgia: http://www.arches.uga.edu/~esudduth/
- Alabama: http://www.aces.edu/waterquality/streams/general.htm.
- Center for Watershed Protection: http://www.cwp.org
- Northern Virginia Soil & Water Conservation District (NVSWCD): www.co.fairfax.va.us/nvswcd/
- MD Waterway Construction Guidelines: http://www.mde.state.md.us/Programs/WaterPrograms/Wetlands_Waterways/documents_information/guide.asp
- PA Clear Water Conservancy: http://www.clearwaterconservancy.org/StrRestorProject.htm
- PA Dept of Environmental Protection: http://www.dep.state.pa.us
- Patrick Center's Institute for River Restoration: http://www.acnatsci.org/research/pcer/institute.html
- Oregon Watershed Enhancement Board: http://www.oweb.state.or.us/index.shtml
- Washington Department of Fish and Wildlife Habitat Program: http://www.wa.gov/wdfw/habitat.htm
- Stream Corridor Restoration Manual: http://www.usda.gov/stream_restoration/newgra.html

Acknowledgments

The committee would like to acknowledge the following people for their assistance and insight in developing this manuscript:

Andrew Burg, Mecklenburg County Stormwater Services; Eve Brantley and Steve Foster, Alabama Cooperative Extension; Joey Woodard, Tennessee Department of Environment and Conservation; Sandi Formica, Arkansas Department of Environmental Quality; Dan Clinton, Earth Tech; Kurt Malchow, California Department of Water Resources; Ann Riley, Waterways Restoration Institute; Amin Wahab, Portland Bureau of Environmental Services; Andrew Harris, City of Lake Oswego; Mike Kelly, City of Austin Watershed Division.

References

Booth, D. et al. (2002) "Urban Stream Rehabilitation in the Pacific Northwest," *Proceedings of Northwest Stream Restoration Design Symposium*, Stevenson, Washington.

Brown, K. B. (2000). *Urban stream restoration practices: An initial assessment*, Center for Watershed Protection, Maryland.

Burg, Andrew (2002). *Personal Communication*, Charlotte/Mecklenburg Storm Water Services, North Carolina

Cahoon, B. and M. Kline (2002). "Alternatives for River Corridor Restoration," *Vermont Dept of Environmental Conservation*, Waterbury, Vermont.

Copeland, R., D.N. McComas, C.R. Thorne, P.J. Soar, M.M. Jonas, and J.B. Fripp (2001), *Hydraulic Design of Stream Restoration Projects*, Coastal Hydraulics Laboratory, Vicksburg, MS.

Day, David (2002). *Personal Communication*, Illinois DNR, Springfield, IL

Denniston, John (1999). *"Stream Channel Restoration and Stabilization in Maryland, Stream Restoration of Little Paint Branch at Beltsville Community Park,"* Maryland State Highway Administration.

Doll, Barbara and Dan Clinton (2002). *Personal Communication*, N.C. State University.

Doneker, R., B. Henderson, and A. Harris (2002), "Restoration of Springbrook Creek in Lake Oswego, Oregon," *Proceedings of the 9th International Conference on Urban Drainage*, Portland, Oregon.

Federal Interagency Stream Restoration Working Group (1998). *Stream Corridor Restoration: Principles, Processes, and Practices.*

Fischenich, Craig (2001), "Technologies for urban stream restoration and watershed management," *Ecosystem Management and Restoration*, EMRRP Bulletin No. 01-1.

Formica, Sandi (2002). *Personal Communication*, Arkansas Department of Environmental Quality, Environmental Preservation Division, Little Rock, Arkansas.

Gettys, Paul (2002). *Personal Communication*, Catawba River Task Force.

Gresham, D. (2002) "Habitat in Restoration Design: Guidelines to Applications," *Proceedings of Northwest Stream Restoration Design Symposium*, Stevenson, Washington.

Gritzuk, M. et al. (2001) "Tres Rios, A Unique Habitat Restoration Project," *Proceedings of the Wetlands Engineering and River Restoration Conference*, Reno, Nevada.

Grossman, E. (2002). *Watershed, The Undamming of America*, Perseus Book Group, NY.

Harris, A. (2002) "Springbrook Creek Urban Stream Restoration, Lake Oswego," *Proceedings of Northwest Stream Restoration Design Symposium*, Stevenson, Washington.

Hunter, M.R., and C. L. Thrush (2002). "Restoring Denver area streams and gulches," *Proceedings of the 9th International Conference on Urban Drainage*, Portland, Oregon.

Johnson, P., R. L. Tereska, and E. R. Brown (2002), "Using Technical Adaptive Management to Improve Design Guidelines for Urban Instream Structures," *Journal of the American Water Resources Association*, Vol. 38, No. 4.

Keystone Stream Team (2003), *Guidelines for Natural Stream Channel Design for Pennsylvania Waterways*, Canaan Valley Institute, PA.

Kohlenburg, B. and K. MacKenzie (2002), "Restorative Maintenance of the South Platte River in the Denver Metropolitan Area," *Proceedings of the 9th International Conference on Urban Drainage*, Portland, Oregon.

Latimore, J.A., K.J. Gerard, R.A. Hellenthal (2001). "Effectiveness of stream restoration techniques for enhancing habitat quality and benthic invertebrate populations," *63rd Midwest Fish and Wildlife Conference - Transitions in the Conservation Landscape*; University of Iowa and the Iowa DNR; Des Moines, Iowa.

Lendloff, Stephanie (2002) "Social Components of Dam Removal," *University of Wisconsin Dam Removal Course Proceedings*, Waterville, New Hampshire.

Llyod, D.W., and P.A. Hindeman (2002). "Major stream restoration projects in the Denver metropolitan area," *Proceedings of the 9th International Conference on Urban Drainage*, Portland, Oregon.

Malchow, Kurt (2002). *Personal Communication*, California Water Resources Department, Urban Streams Restoration Program.

North Carolina Division of Water Quality, Wetlands Restoration Program (2001). *Watershed Restoration Plan for the Catawba River Basin*, NC Department of Environment and Natural Resources. 44 pp.

Newbury, R.W., and M.N. Gaboury (1993), *Stream analysis and fish habitat design: a field Manual*, Newbury Hydraulics Ltd., Gibsons, British Columbia, Canada.

Pinkham, Richard (2000). *Daylighting: New Life for Buried Streams*. Rocky Mountain Institute, Snowmass, CO. 63 pp.

Reichheld, E. et al. (2002). "Watershed Approaches to Stream Restoration: New York Department of Environmental Protection Water Supply Watershed Management Experiences," *Mid Atlantic/Northeast Training Workshop on Stream, Floodplain, and Wetland Restoration*, Assoc. of State Wetland Managers, Bear Mountain, New York.

Riley, Ann L. (2002). "A Primer on Stream and River Protection for the Regulator and Program Manager," *Technical Reference Circular W.D. 02-#1*, San Francisco Bay Region, California Regional Water Quality Control Board.

Rodríguez, J.F., M.H. Garcia, F.A. Bombardelli, J.M. Guzman, B.L. Rhoads, and E.E. Herricks (2000) "Naturalization of urban streams using in-channel structures." *Procedings of the ASCE Joint Conference on Water Resources Engineering and Water Resources Planning and Management*, Minneapolis, Minnesota.

Rosgen, D.L. (1997). "A geomorphological approach to restoration of incised rivers," *Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision*, pp. 12-22.

Schwartz, J.S., E.E. Herricks, J.F. Rodriguez, B.L. Rhoads, M.H. Garcia, and F.A. Bombardelli (2002). "Physical habitat analysis and design of in-channel structures on a Chicago, IL urban drainage: a stream naturalization design process." *Proceedings of the 9th International Conference on Urban Drainage*, Portland, Oregon.

Vermont Water Quality Division (2000) "Vermont Regional Hydraulic Geometry Curves (Provisional)," *Vermont Dept of Environmental Conservation*, Waterbury, Vermont.

Wahab, A. (2002) "Stream Restoration in the Fanno and Tryon Creek Watersheds in Portland," *Proceedings of Northwest Stream Restoration Design Symposium*, Stevenson, Washington.

Warren, Scott et al, (2002). "Salt Marsh Restoration in Connecticut: 20 Years of Science and Management", *Restoration Ecology*, Vol 10 No 3.

Wildman, L. and J. MacBroom (2000). "Dam Removal – A Tool for River Restoration on the Naugatuck River," *Proceedings of the ASCE Joint Conference on Water Resource Engineering and Water Resource Planning*, Minneapolis, Minnesota.